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Analysis of Heterotic Potential for Yield and Its Contributing Traits in Wheat (*Triticum aestivum* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. Author BRKR wrote the first draft of the manuscript. Author BK wrote the protocol and designed the study and managed the analyses of the study. Author RK performed the statistical analysis and author HT cited references. All authors read and approved the final manuscript.

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ABSTRACT

Fifty-six genotypes were evaluated comprising 45 hybrids, 10 parents and 1 standard check (HD2968) were evaluated in a randomized block design (RBD) with three replications for 12 traits *viz.* Days to 50 % flowering, days to maturity, plant height, number of tillers per plant, spikelets per spike, ear length, spike density, number of ears per plant, number of grains per ear, seed index, grain yield per plant and harvest index to study the magnitude and direction of heterosis for yield and earliness in wheat. Significant heterosis was found over mid parent and commercial checks for all the traits studied in desirable direction. The findings revealed highly significant differences between parents and F_1's as well as among parents for the majority of attributes. In the present research investigation, the number of days taken for 50 % flowering and days to maturity was selected as indicative of earliness. Among 45 crosses, K1317 x HD2967 expressed negative

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significant heterosis over mid parent and standard check respectively, for days to 50% flowering while Cross HD3059 x DBW3059 revealed highly significant negative heterosis for days to maturity. In present research, the highest positive and significant heterosis over mid parent was exhibited by cross DBW187 x HI153 followed by DBW187 x DBW3059, HD3294 x DBW3059. The cross DBW187 x DBW3059 followed by DBW187 x HD3059, HD3294 x K1601 shows highly positive heterotic percent for grain yield per plant over standard check. These hybrids may further be tested over various locations before release for commercial cultivation. High estimates of heterosis obtained in hybrid combinations revealed considerable genetic divergence among the parental lines and reveals good scope for commercial exploitation of heterosis in wheat.

Keywords: Heterosis; earliness; grain yield per plant; mid parent; standard check; genetic divergence.

1. INTRODUCTION

Wheat (*Triticum aestivum* L.) is an important cereal crop that was one of the first to be domesticated roughly ten thousand years ago. It is a self-pollinated cereal crop of the Poaceae family and the genus *Triticum*, which includes a wide range of staple crops. It has also been dubbed the "King of Cereals" due to its huge land area, outstanding production and substantial involvement in the global food grain trade. The FAO estimates global wheat output at 775.4 mt for 2021-22, with India's share at 103.9 mt [1]. It was initially cultivated in the Neolithic period in the Nile valley by 5000 B.C., and it is evident that it was afterwards grown in other areas (for example, the Indus and Euphrates valleys by 4000 B.C., China by 2500 B.C. and England by 2000 B.C. indicates that it expanded from Mediterranean domestication sites. Wheat has been a major component of West Asian and European civilizations [2]. Wheat has been the primary source of bread in Europe and the Middle East since the beginning of agriculture.

Sakamura [3] reported the chromosomal number for each set (genome) of members known to have been recognised as early as 1918. He divided wheat into three categories: diploids (2n=14), tetraploids (2n=28), and hexaploids (2n=42). The most widely farmed and consumed wheat types are *Triticum aestivum, Triticum durum* and *Triticum dicoccum* [4]. The most important species is bread wheat, which accounts for 90 percent of all farmed land globally. *T. dicoccum* wheat accounts for less than 1% of total area, whereas durum wheat accounts for around 4% of total wheat acreage [5].

The degree of heterosis provides a foundation for genetic diversity and a guide for selecting desirable parents for developing superior F_1 hybrids to exploit hybrid vigour and for developing gene pools for future breeding programmes [6]. With this in mind, the current study was carried out to determine the magnitude of heterosis for earliness, fruit yield and its attributes traits in wheat.

2. MATERIALS AND METHODS

The current investigation was carried out at the agriculture research farm, Lovely Professional University, Phagwara, Punjab during the *Rabi* seasons of 2022. The experiment took place on black cotton soil. The experimental material included 10 parental lines, that were crossed in diallel fashion (excluding reciprocals) and 45 crosses were produced. The hand emasculation method was adopted for crossing. All the F_1 and self-seeds of parents were stored properly in packets for sowing in the *rabi* 2022. The 10 parental lines along with 45 F_1's and checks were evaluated in a randomized block design with three replications for 12 traits *viz.* Days to 50 % flowering, days to maturity, plant height, number of tillers per plant, spikelets per spike, ear length, spike density, number of ears per plant, number of grains per ear, seed index, grain yield per plant and harvest index were used in the experiment to study heterosis. Panse and Sukhatme's [7] method of analysis of variance (ANOVA) for Randomized Block Design was used (1985). Fonseca and Peterson (1968) [8] and Meredith and Bridge [9] provided methods for calculating mid parent and standard heterosis respectively.

Table 1. Material used in breeding program

Sr. No.	Genotypes
1	K1317
2	HD2967
3	DBW187
4	HD3294
5	K0307
6	K1601
7	DBW107
8	HD3059
9	DBW3059
10	HI1563
check	**HD2968**

Table 2. List of crosses made

1	K1317 X HD2967	24	DBW187 X HI153
2	K1317 X DBW187	25	HD3249 X K0307
3	K1317 X HD3294	26	HD3249 X K1601
4	K1317 X K0307	27	HD3249 X DBW107
5	K1317 X K1601	28	HD3249 X HD3059
6	K1317 X DBW107	29	HD3249 X DBW3059
7	K1317 X HD3059	30	HD3249 X HI153
8	K1317 X DBW3059	31	K0307 X K1601
9	K1317 X HI153	32	K0307 X DBW107
10	HD2967 X DBW187	33	K0307 X HD3059
11	HD2967 X HD3294	34	K0307 XDBW3059
12	HD2967 X K0307	35	K0307 X HI153
13	HD2967 X K1601	36	K1601 X DBW107
14	HD2967 X DBW107	37	K1601 X HD3059
15	HD2967 X HD3059	38	K1601 X DBW3059
16	HD2967 X DBW3059	39	K1601 X HI153
17	HD2967 X HI153	40	DBW107 X HD3059
18	DBW187 X HD3294	41	DBW107 X DBW3059
19	DBW187 X K0307	42	DBW107 X HI153
20	DBW187X K1601	43	HD3059 X DBW3059
21	DBW187X DBW107	44	HD3059 X HI153
22	DBW187 X HD3059	45	DBW3059 X HI153
23	DBW187 X DBW3059	**check**	**HD2968**

2.1 Estimation of Heterosis

The estimation of heterosis was estimated in relation to mid-parent and standard check hybrid values. They were thus, calculated as per cent increase or decrease in hybrid (F_1) over its mid parent (MP) and standard check (SH) values in the desirable direction was calculated using the following formula given by Fonseca and Patterson [8].

Heterosis over mid parent (MP):

$$\mathrm{MP\%} = \frac{\mathrm{F1} - \mathrm{MP}}{\mathrm{MP}} \mathrm{x}\ 100$$

Where,

F_1 = Mean performance of F_1 hybrid
MP = Mean performance of mid parent

Heterosis over standard check (SH):

$$\mathrm{SC\%} = \frac{\mathrm{F1} - \mathrm{SH}}{\mathrm{SH}} \mathrm{x}\ 100$$

Where,

F_1 = Mean performance of F_1 hybrid
SH = Mean performance of standard check

3. RESULTS AND DISCUSSION

3.1 Analysis of Variance

The phenomenon of heterosis is nowadays used as an important and efficient tool for achieving higher yields. The results of the analysis of variance for parents and F_1's respectively presented in Table 3. The findings revealed highly significant differences between parents and F_1's as well as among parents, for the majority of attributes. These significant differences indicate a considerable amount of heterotic response in these attributes suggesting the presence of significant variability in both parents and crosses. The selection of parents based on morphological differences was validated through the analysis of variance. Chaudhary et al. [6], Kumar et al. [10], Burdak et al. [11] and Santhoshini et al. [1] reported similar observations.

3.2 Analysis of Heterosis

Heterosis is the superiority of F_1 hybrid over the mid parent or better parent and standard check variety. It is expressed by allelic and non-allelic interaction of genes in either homozygote dominant or heterozygote conditions under the influence of particular environment [12]. Heterosis observed in many crop species, and has been the objective of considerable importance to plant breeders as a source of increasing productivity of crop plants. It is now well-established fact that heterosis does occur with selective combination of parents. Very little emphasis is diverted to study the heterotic effects in heat stress conditions. The present design to identify the cross combinations which express desirable heterosis for yield and yield contributing traits. The heterotic performance of f_1 hybrids for yield traits is presented in Table 4.

3.2.1 Days to 50 % flowering

Negative heterosis for days taken to 50 % flowering is desirable if these have significant correlation with early flowering plants. In the present research investigation, the number of days taken for 50 % flowering is selected as indicative of earliness. Fifteen crosses over mid parent and twenty-two crosses over standard check (HD2968) respectively, revealed highest significant negative heterosis where K1317 x HD2967 followed by DBW187 x k1601, K1601 x DBW107 are best 3 crosses over mid parents. The cross K1317 x HD2967 followed by DBW187 x DBW3059, HD3059 x HI153 over standard check. These results are in conformation with results of Jatoi et al. [13] and Nagar et al. [14].

3.2.2 Days to maturity

Among 45 crosses, twelve and sixteen crosses expressed negative significant heterosis over mid parent and standard check respectively. Cross HD3059 x DBW3059 revealed highest significant negative heterosis followed by K1601 x HD3059, DBW187 x DBW3059 over mid parent. The highest significant negative heterosis is observed in cross DBW107 x HD3059 followed by HD3294 x DBW3059, K0307 x HD3059 over standard check. These findings are in accordance with Kumar et al. [10], Jatoi et al. [13] and Rajput and kandalkar [15].

Table 3. Analysis of variance for 12 characters in a diallel cross of 10 parents and their F_1's in wheat

Source of variation	Df	DFF	DM	PH	NTP	NSP	EL
Replications	2	43.824*	1.145	28.697	0.183	1.018	0.003
Treatments	54	17.748**	31.085**	80.639*	2.330**	3.182**	1.193**
Error	108	8.953	11.633	48.888	0.072	0.512	0.108
Source of variation	**Df**	**SD**	**NEPP**	**NGPE**	**SI**	**GYP**	**HI**
Replications	2	0.001	0.014	1.937	1.797	0.596	21.568
Treatments	54	0.023**	6.407**	26.614**	21.656**	19.940**	51.934
Error	108	0.006	0.158	3.457	1.343	0.667	48.226

**Significant at 5 per cent level, ** Significant at 1 per cent level*

3.2.3 Plant height

In wheat dwarf plants are required because tall plant are more prone to lodging therefore negative heterosis in this case is desirable. Among 45 crosses nine, fourteen crosses showed negative significant heterosis over mid parent and standard check, HD2968. The highest significant negative heterosis was observed in K1601 x DBW3059 followed by DBW187 x DBW3059, K0307 x DBW3059 over mid parent and the cross K1317 x HD3059 followed by DBW187 x K0307, HD3249 x HD3059 over standard check. Similar results were reported by Nagar et al. [14], Rajput and Kandalkar [15], Kamal et al. [16] and Kaur et al. [17].

3.2.4 Number of tillers per plant

Number of effective tillers per plant is highly desirable trait and which directly contribute to yield per plant hence positive heterotic effect is desirable. For number of tillers mid parent heterosis and standard check, HD2968 taken into consideration. Among 45 crosses twelve, fifteen depicted significant and positive values of heterosis for number of tillers per plant. In present research the highest positive and significant heterosis over mid parent was exhibited by cross. The hybrids HD3249 x K1601 shows highly significant positive heterosis followed by DBW187 x HD3294, HD2967 x HD3249 over mid parent. Hybrid K0307 x DBW3059 (59.36) shows highly significant positive heterosis for number of tillers per plant followed by DBW187 x HD3249, HD3294 x K1601 over standard check HD2968.shows highly positive values for number of spikelet's per plant over standard check. Multiple researchers have consistently reported a substantial increase in the number of effective tillers per plant in wheat, indicating significant positive heterosis. Kumar at el. [10], Nagar et al. [14], Askander et al. [18] and Yadav et al. [19].

3.2.5 Number of spikelets per spike

Seventeen, eleven hybrids among 45 crosses recorded positively significant heterosis over mid parent and standard check HD2968 respectively, for number of spikelet's per spike. In present research the highest positive and significant heterosis over mid parent was exhibited by cross HD2967 x DBW187, followed by HD2967 x DBW107, K1317 x DBW187. The cross HD2967 x DBW187 followed by K1317 x DBW187, HD2967 x DBW107 (12.18) shows highly positive values for number of spikelet's per plant over standard check in accordance with the results of Kumar at el. [10], Nagar et al. [14] and Yadav et al. [19].

3.2.6 Ear length

Among 45 crosses evaluated, seventeen, twenty-one hybrids recorded positively significant heterosis over mid parent and standard check HD2968 respectively, for ear length. In present research the highest positive and significant heterosis over mid parent was exhibited by cross DBW187 x HD3294 followed by DBW187 x K0307, K1317 x DBW187, the cross DBW187 x HD3294 followed by K1317 x DBW187, HD2967 x DBW107 shows highly positive values for ear length over standard check. These results are with the agreement of Kumar at el. [10], Nagar et al. [14], Kamal et al. [16] and Askander et al. [18].

3.2.7 Spike density

Among 45 crosses evaluated, fifteen, eleven hybrids recorded positively significant heterosis over mid parent and standard check HD2968 respectively, for spike density. In present research the highest positive and significant heterosis over mid parent was exhibited by cross HD2967 x K1601 followed by DBW3059 x HI153, HD2967 x DBW3059. The cross HD2967 x K1601 followed by K1601 x HD3059, DBW3059 x HI153 shows highly positive values for spike density over standard check. Same results has been highlighted by Kumar at el. [10].

3.2.8 Number of ears per plant

Among 45 crosses evaluated, fourteen, eight hybrids recorded positively significant heterosis over mid parent and standard check HD2968 respectively, for number of ears per plant. The magnitude of heterosis ranges from (-12.14) to (17.84) over mid parent. In present research the highest positive and significant heterosis over mid parent was exhibited by cross DBW187 x K0307 followed by DBW187 x DBW3059, K1317 x HD2967. The cross DBW187 x K0307 followed by K1317 x HD2967, HD3294 x DBW107 shows highly positive values for number of ears per plant over standard check. These results are in accordance with Kaur et al. [17], Yadav et al. [19], Abdelkhalik et al. [20], Shrief at el. (2019).

Table 4. Estimation of heterosis over mid parent and standard heterosis of various characters in wheat

Sr. No	Cross No	Genotype	Days to 50 % flowering		Days to maturity		Plant height (cm)		Number of tillers per plant	
			MPH	SH	MPH	SH	MPH	SH	MPH	SH
1	C1	K1317 X HD2967	-9.27**	-11.22**	3.03	1.91	3.47	-7.56	-2.3	13.37
2	C2	K1317 X DBW187	-0.85	-3.63	5.13**	3.27	-4.57	-10.1	-14.53	6.15
3	C3	K1317 X HD3294	-4.24	-6.93**	-2.37	-4.63*	-1.23	-15	-2.07	13.9
4	C4	K1317 X K0307	-5.3*	-8.58**	1.41	-1.91	3.55	-9.55	-8.06	14.44
5	C5	K1317 X K1601	-4.87*	-6.6*	-0.41	-1.36	-13.3	-18.6*	-4.11	12.3
6	C6	K1317 X DBW107	-4.24	-6.93**	0.28	-2.18	-14.38	-24.03**	-9.76	11.23
7	C7	K1317 X HD3059	-3.59	-6.93**	-1.22	-1.09	-13.48	-27.92**	-11.16	6.42
8	C8	K1317 X DBW3059	-2.96	-7.92**	-0.83	-1.91	-14.68	-16.3	-10.56	10.96
9	C9	K1317 X HI153	-5.04*	-9.9**	0.42	-2.18	7.08	-7.47	-12.65	8.02
10	C10	HD2967 X DBW187	-3.68	-4.95	2.87	2.45	-5.17	-8.25	1.66	22.99
11	C11	HD2967 X HD3294	-5.35*	-6.6*	3.71	2.72	-3.11	-14.16	27.66**	44.39**
12	C12	HD2967 X K0307	-5.05*	-6.93**	0.28	-1.63	-15.49	-24.03**	-5.62	14.44
13	C13	HD2967 X K1601	-5.96**	-6.27*	-2.31	-1.91	-14.24	-17.31	7.04	21.93
14	C14	HD2967 X DBW107	-6.69**	-7.92**	-3.58	-4.63*	-5.53	-13.77	2.45	22.99
15	C15	HD2967 X HD3059	-4.04	-5.94*	-3.89*	-2.45	3.8	-10.88	3.67	20.86
16	C16	HD2967 X DBW3059	-4.11	-7.59**	-1.09	-0.82	-17.13*	-16.59	3.1	24.6*
17	C17	HD2967 X HI153	-3.08	-6.6*	2.62	1.36	2.55	-8.77	0.78	21.39
18	C18	DBW187 X HD3294	-1.68	-3.63	2.77	1.09	-11.95	-17.69	27.89**	55.08**
19	C19	DBW187 X K0307	-4.75*	-7.26**	-0.42	-3	-23.26**	-27.27**	13.22	46.52**
20	C20	DBW187X K1601	-8.67**	-9.57**	-1.09	-1.36	-18.14*	-17.08	-9.75	10.16
21	C21	DBW187X DBW107	-3.7	-5.61*	-3.74	-5.45*	-9.71	-13.18	-14.08	10.16
22	C22	DBW187 X HD3059	-5.42*	-7.92**	-5.95**	-5.18*	-3.42	-12.37	-15.54	5.35
23	C23	DBW187 X DBW3059	-6.9**	-10.89**	-0.96	-1.36	-26.55**	-22.5*	-16.27	8.02
24	C24	DBW187 X HI153	-4.48	-8.58**	2.78	0.82	-3.84	-9.77	-20.17*	2.67
25	C25	HD3294 X K0307	0	-2.64	2.67	-0.54	-6.71	-19.19*	25.41**	52.41**
26	C26	HD3294 X K1601	-2	-2.97	-0.82	-1.63	-15.65	-21.43*	35.36**	54.55**
27	C27	HD3294 X DBW107	-5.05*	-6.93**	-2.93	-5.18*	-11.31	-21.95*	16	39.57**
28	C28	HD3294 X HD3059	-4.41	-6.93**	-5.43**	-5.18*	2.58	-15.29	18.54*	38.5**
29	C29	HD3294 X DBW3059	-1.03	-5.28*	-5.64**	-6.54**	-24.91**	-26.88**	16.11	40.64**
30	C30	HD3294 X HI153	-0.69	-4.95	2.79	0.27	-3.94	-17.69	12.07	35.29**
31	C31	K0307 X K1601	-3.02	-4.62	-0.14	-1.91	-6.88	-12.05	19.78*	46.52**
32	C32	K0307 X DBW107	-2.71	-5.28*	-1.97	-5.18*	-7.8	-17.66	13.22	45.45**
33	C33	K0307 X HD3059	4.44	0.99	-5.62**	-6.27**	4.82	-12.08	14.65	43.32**
34	C34	K0307 XDBW3059	2.43	-2.64	0.56	-1.36	-23.66**	-24.68**	23.27**	59.36**
35	C35	K0307 X HI153	-1.39	-6.27*	3.81	0.27	-0.67	-13.6	9.96	41.71**

Sr. No	Cross No	Genotype	Days to 50 % flowering		Days to maturity		Plant height (cm)		Number of tillers per plant	
			MPH	SH	MPH	SH	MPH	SH	MPH	SH
36	C36	K1601 X DBW107	-7.33**	-8.25**	-3.99*	-4.9*	-13.91	-17.5	-5.96	13.9
37	C37	K1601 X HD3059	-2.68	-4.29	-6.97**	-5.45*	-8.46	-17.24	-4.09	12.83
38	C38	K1601 X DBW3059	-2.05	-5.28*	-1.76	-1.36	-29.57**	-25.91**	-9.65	10.16
39	C39	K1601 X HI153	-4.44	-7.59**	1.38	0.27	-21.88**	-26.95**	-11.55	7.49
40	C40	DBW107 X HD3059	-3.73	-6.27*	-8.3**	-8.17**	-0.84	-15.45	-12.53	8.29
41	C41	DBW107 X DBW3059	-4.14	-8.25**	-4.96*	-5.99**	-16.92*	-16.88	-17.75*	5.35
42	C42	DBW107 X HI153	0.69	-3.63	-2.38	-4.9*	-5.38	-16.4	-20.42*	1.6
43	C43	HD3059 X DBW3059	0	-4.95	-7.11**	-5.72*	-13.4	-18.05*	-7.3	15.51
44	C44	HD3059 X HI153	-5.21*	-9.9**	-5.18**	-5.18*	5.97	-12.11	-26.16**	-8.29
45	C45	DBW3059 X HI153	1.77	-4.95	2.07	0.82	-13.72	-15.68	-16.75*	6.95

**Significant at 5 per cent level, ** Significant at 1 per cent level*

Table 4. Estimation of heterosis over mid parent and standard heterosis of various characters in wheat (Cont…..)

Sr. No	Cross No	Genotype	Number of spikelets per plant		Ear length (cm)		Spike density		Number of ears per plant	
			MPH	SH	MPH	SH	MPH	SH	MPH	SH
1	C1	K1317 X HD2967	8.65**	3.69	0.67	8.66**	1.49	4.18	12.32**	27.57**
2	C2	K1317 X DBW187	18.68**	18.59**	6.73**	17.33**	-2.89	-0.15	-7.83*	6.58
3	C3	K1317 X HD3294	0.56	1.44	2.18	10.11**	-4.63	0.65	-9.48**	4.12
4	C4	K1317 X K0307	1.93	1.44	5.72*	13.36**	-5.68*	-2.29	21.21**	39.92**
5	C5	K1317 X K1601	-1.24	2.4	1.02	6.86*	2.67	4.68	-10.51**	1.65
6	C6	K1317 X DBW107	0.73	-0.48	-4.15	8.3**	-4.36	0.34	-11.27**	2.06
7	C7	K1317 X HD3059	0.08	-0.8	-5.88*	3.97	-1.81	4.19	-11.62**	3.29
8	C8	K1317 X DBW3059	7.54**	1.76	-2.03	4.69	5.6*	6.14	8.63**	39.92**
9	C9	K1317 X HI153	-2.65	-2.72	-3.3	0.36	2.9	5.85	-21.74**	3.7
10	C10	HD2967 X DBW187	44.56**	36.22**	1.16	10.11**	4.18	6.6*	-1.62	0
11	C11	HD2967 X HD3294	6.4*	1.28	2.2	9.03**	-3.42	1.44	2.65	3.7
12	C12	HD2967 X K0307	7.94**	1.28	2.72	9.03**	-1.61	1.43	-1.42	0
13	C13	HD2967 X K1601	4.33	2.24	2.41	7.22*	17.84**	19.55**	3.72	3.29
14	C14	HD2967 X DBW107	20.48**	12.18**	3.23	15.52**	-6.22*	-2.09	1.02	2.06
15	C15	HD2967 X HD3059	6*	-0.96	-2.64	6.5*	-3.77	1.61	-2	0.82
16	C16	HD2967 X DBW3059	14.23**	1.6	-5.8*	-0.36	11.39**	11.39**	-9.32**	4.12
17	C17	HD2967 X HI153	3.57	-2.4	-6.85**	-4.33	8.91**	11.48**	-8.68**	8.23
18	C18	DBW187 X HD3294	4.5	4.17	10.96**	20.58**	-10.28**	-5.61	-2.59	0.41
19	C19	DBW187 X K0307	5.95*	4.17	8.18**	16.97**	-5.75*	-2.68	35.19**	39.92**
20	C20	DBW187X K1601	2.42	4.97	6.94**	14.08**	-1.13	0.47	1.62	3.29

Sr. No	Cross No	Genotype	Number of spikelets per plant		Ear length (cm)		Spike density		Number of ears per plant	
			MPH	SH	MPH	SH	MPH	SH	MPH	SH
21	C21	DBW187X DBW107	4.76	2.24	0.16	14.08**	-6.4*	-2.11	7.39*	10.7*
22	C22	DBW187 X HD3059	4.26	2.08	-2.11	9.03**	-3.32	2.26	0	4.94
23	C23	DBW187 X DBW3059	11.84**	4.49	-1.51	6.14*	7.3**	7.49*	19.72**	39.92**
24	C24	DBW187 X HI153	1.62	0.32	2.41	7.22*	-0.31	2.21	-17.75**	-0.82
25	C25	HD3294 X K0307	-2.99	-3.69	6.64**	13**	-12.14**	-6.89*	2.4	5.35
26	C26	HD3294 X K1601	-3.64	-0.32	9.15**	14.08**	-8.55**	-4.58	4.68	5.76
27	C27	HD3294 X DBW107	-1.63	-3.04	-2.75	8.66**	-9.15**	-2.53	7.23*	9.88*
28	C28	HD3294 X HD3059	-2.92	-4.01	-3.47	5.42	-8.36**	-0.58	1.38	5.76
29	C29	HD3294 X DBW3059	3.06	-2.72	0.17	5.78	-2.34	0.48	-9.03**	5.76
30	C30	HD3294 X HI153	-5.63*	-5.93*	1.41	3.97	-6.11*	-1.19	-15.95**	0.82
31	C31	K0307 X K1601	-2.2	-0.16	6.25*	10.47**	-3.59	-1.27	-1.01	0.41
32	C32	K0307 X DBW107	-0.58	-3.37	-2.27	8.66**	-7.84**	-2.9	-4	-1.23
33	C33	K0307 X HD3059	0.08	-2.4	-1.66	6.86*	-6.39*	-0.26	-2.95	1.65
34	C34	K0307 XDBW3059	5.65*	-1.71	-4.47	0.36	5.93*	6.95*	-12.17**	2.47
35	C35	K0307 X HI153	-2.69	-4.33	-4.42	-2.53	3.75	7.18*	-14.53**	2.88
36	C36	K1601 X DBW107	-4.19	-2.88	-0.99	8.66**	-5.91*	-2.42	2.65	3.7
37	C37	K1601 X HD3059	-2.13	-0.48	-2.36	4.69	10.19**	15.59**	-11.2**	-8.64*
38	C38	K1601 X DBW3059	1.4	-1.44	-1.05	2.53	5.73*	5	-12.19**	0.82
39	C39	K1601 X HI153	3.52	6.09*	-2.33	-1.81	5.38*	7.13*	-14.58**	1.23
40	C40	DBW107 X HD3059	-6.46*	-9.46**	-14.83**	-2.53	-5.7*	1.72	-0.59	3.7
41	C41	DBW107 X DBW3059	-2.95	-10.42**	-13.03**	-3.61	-0.71	1.55	-12.57**	1.65
42	C42	DBW107 X HI153	-10.51**	-12.66**	-14.91**	-8.3**	-0.55	4.04	-16.98**	-0.41
43	C43	HD3059 X DBW3059	-2.94	-10.1**	-9.67**	-2.17	-3	0.36	-12.2**	3.7
44	C44	HD3059 X HI153	-10.8**	-12.66**	-9.43**	-4.69	-5.33*	0.18	-14.53**	4.12
45	C45	DBW3059 X HI153	-10.46**	-16.35**	-14.74**	-13.36**	13.99**	14.25**	-24**	1.65

**Significant at 5 per cent level, ** Significant at 1 per cent level*

Table 4. Estimation of heterosis over mid parent and standard heterosis of various characters in wheat (Cont…..)

Sr. No	Cross No	Genotype	Number of grains per ear		Seed index (g)		Grain yield per plant (g)		Harvest index (%)	
			MPH	SH	MPH	SH	MPH	SH	MPH	SH
1	C1	K1317 X HD2967	-4.52	-8.9**	1.66	-2.93	11.26**	9.66*	18.85	32.92*
2	C2	K1317 X DBW187	1.17	0.2	0	-5.77*	-23.09**	-17.36**	11.51	21.64
3	C3	K1317 X HD3294	6.41*	-0.2	0.96	-1.54	-13.46**	-11.88**	29.5*	22.11
4	C4	K1317 X K0307	1.58	-1.7	-10.27**	-12.6**	-17.77**	-14.23**	-16.26	-9.34
5	C5	K1317 X K1601	6.39*	0.07	20.92**	15.37**	-5.49	-3.39	-22.5*	-19.27
6	C6	K1317 X DBW107	-4.73	-8.36**	-2.96	-6.59**	-26.91**	-26.24**	-0.54	6.39
7	C7	K1317 X HD3059	28.13**	19.9**	4.92*	-0.24	-25.88**	-22.58**	-22.69*	-10.07
8	C8	K1317 X DBW3059	5.3	-3.46	9.99**	7.4**	-20.69**	-18.93**	10.89	13.5
9	C9	K1317 X HI153	0.78	-3.06	7.82**	3.66	-25.5**	-26.76**	12.97	17.68
10	C10	HD2967 X DBW187	1.09	10.67**	5.07*	0.33	-3.41	-0.13	5.33	19.21
11	C11	HD2967 X HD3294	7.63**	12.16**	1.4	0.16	0.27	-1.96	3.1	1.44
12	C12	HD2967 X K0307	-2.14	4.9	-0.29	-1.63	9.38**	9.66*	0.1	12.46
13	C13	HD2967 X K1601	2.15	6.73*	4.63*	1.14	-4.65	-6.4	2.55	11.03
14	C14	HD2967 X DBW107	8.82**	16.03**	1.79	-0.73	-9.03*	-11.88**	-24.14*	-15.75
15	C15	HD2967 X HD3059	4.57	8.76**	10.3**	6.26**	-10.4**	-10.05*	-32.27**	-18.45
16	C16	HD2967 X DBW3059	1.06	3.19	6.21**	5.04*	-1.6	-3.39	15.37	22.8
17	C17	HD2967 X HI153	-4.36	1.97	3.76	1.06	-7.89*	-13.19**	17.42	27.11*
18	C18	DBW187 X HD3294	7.15**	15.56**	-1.63	-4.07	-19.22**	-13.84**	23.76	18.36
19	C19	DBW187 X K0307	-5.06*	5.23	-6.09**	-8.54**	2.87	12.27**	26.6*	38.75**
20	C20	DBW187X K1601	-1.41	6.59*	0.98	-3.66	-24.39**	-19.06**	7.49	13.41
21	C21	DBW187X DBW107	-6.28**	3.33	-3.13	-6.75**	-8.64**	-3.39	18.84	28.71*
22	C22	DBW187 X HD3059	0.92	8.63**	6.28**	1.06	20.79**	31.98**	-13.46	1.83
23	C23	DBW187 X DBW3059	-3.57	1.97	2.75	0.33	25**	33.81**	19.47	23.87
24	C24	DBW187 X HI153	-8.26**	1.15	0.55	-3.33	25.44**	29.37**	4.04	9.77
25	C25	HD3249 X K0307	2.51	8.22**	-8.2**	-7.56**	23.71**	28.07**	30.96*	24.16
26	C26	HD3249 X K1601	6.94**	9.99**	-2.55	-3.82	24.45**	26.24**	29.54*	17.52
27	C27	HD3249 X DBW107	-0.55	4.42	10.49**	10**	23.21**	23.37**	30.64*	22.17
28	C28	HD3249 X HD3059	7.17**	9.71**	0.83	-0.81	20.28**	24.67**	4.91	7.92
29	C29	HD3249 X DBW3059	2.84	3.33	-3.91	-3.01	23.94**	25.72**	46.04**	29.82*
30	C30	HD3249 X HI153	-0.03	4.96	-3.92	-4.47	-14.32**	-16.45**	16.04	5.26
31	C31	K0307 X K1601	-7**	-1.56	-7.63**	-8.94**	16.21**	20.76**	-0.41	4.26
32	C32	K0307 X DBW107	-8.34**	-1.02	-8.83**	-9.35**	12.09**	15.01**	28.68*	38.3**
33	C33	K0307 X HD3059	-8.51**	-3.6	-7.24**	-8.86**	10.46**	17.23**	-24.26*	-11.5
34	C34	K0307 XDBW3059	-5.06*	-1.77	-9.52**	-8.78**	12.31**	16.71**	-2.39	0.4
35	C35	K0307 X HI153	-5.69*	1.83	-13.96**	-14.55**	-13.84**	-13.84**	10.18	15.33

Sr. No	Cross No	Genotype	Number of grains per ear		Seed index (g)		Grain yield per plant (g)		Harvest index (%)	
			MPH	SH	MPH	SH	MPH	SH	MPH	SH
36	C36	K1601 X DBW107	-3.9	1.15	7.63**	4.88*	-5.58	-5.09	32.34**	36.84**
37	C37	K1601 X HD3059	2.12	4.82	7.35**	3.33	-8.28*	-4.57	20.33	35.67*
38	C38	K1601 X DBW3059	1.89	2.65	0.62	-0.57	1.41	3.26	21.34	19.86
39	C39	K1601 X HI153	-5.45*	-0.48	-0.5	-3.17	-6.27	-8.22*	35.07**	35.87**
40	C40	DBW107 X HD3059	-13.91**	-9.78**	2.05	-0.89	-23.89**	-21.8**	17.42	35.67*
41	C41	DBW107 X DBW3059	-4.59	-1.83	-4.16*	-4.47	-20.13**	-19.71**	7.98	9.67
42	C42	DBW107 X HI153	-7.91**	-1.09	3.52	1.63	-25.81**	-28.33**	-8.98	-5.9
43	C43	HD3059 X DBW3059	3.05	3.33	20.43**	18.62**	0.25	4.31	24.74*	38.37**
44	C44	HD3059 X HI153	-4.44	0.14	18.61**	15.04**	-6.52	-6.4	9.18	23.1
45	C45	DBW3059 X HI153	-4.46	-1.7	10.9**	10.41**	4.67	2.48	9.5	8.15

**Significant at 5 per cent level, ** Significant at 1 per cent level*

3.2.9 Number of grains per ear

More number of seeds per spike is directly responsible for high grain yield and hence, their positive values are always beneficial in wheat. Among 45 crosses evaluated, nineteen, fifteen hybrids recorded positively significant heterosis over mid parent and standard check HD2968 respectively, for number of grains per ear. The magnitude of heterosis ranges from (-13.91) to (28.13) over mid parent. In present research the highest positive and significant heterosis over mid parent was exhibited by cross K1317 x HD3059 followed by HD2967 x HD3294, DBW187 x HD3294. The cross K1317 x HD3059 followed by HD2967 x DBW107 (16.03), DBW187 x HD3294 shows highly positive values for number of grains per ear over standard check. Significant positive mid parent heterosis for I 000-grain weight (g) in wheat has been also reported by Jatoi et al. [13], Gammaal and Yahya (2018), whereas the similar findings over standard check was reported by Nagar et al. [14] and Kumar at el. [10].

3.2.10 Seed index (g)

Among 45 crosses evaluated, twenty-four, nineteen hybrids recorded positively significant heterosis over mid parent and standard check HD2968 respectively, for grain weight. The magnitude of heterosis ranges from (-13.96) to (35.19) over mid parent. In present research the highest positive and significant heterosis over mid parent was exhibited by cross K1317 x K1601 followed by HD3059 x DBW3059, HD3059 x HI153. The cross HD3059 x DBW3059 followed by K1317 x K1601, HD3059 x HI153 shows highly positive values for 1000 grain weight over standard check with similar reports were reported by Jatoi et al. [13], Nagar et al. [14], Askander et al. [18] and Abdelkhalik et al. [20].

3.2.11 Grain yield per plant (g)

The grain yield in wheat holds immense economic significance as it represents the ultimate outcome resulting from the combined and interdependent effects of various contributing traits. Among 45 crosses evaluated, sixteen, twelve hybrids recorded positively significant heterosis over mid parent and standard check respectively, grain yield per plant. The magnitude of heterosis ranges from (-26.91) to (25.44) over mid parent. In present research the highest positive and significant heterosis over mid parent was exhibited by cross DBW187 x HI153 followed by DBW187 x DBW3059, HD3294 x DBW3059. The cross DBW187 x DBW3059 followed by DBW187 x HD3059, HD3294 x K1601 shows highly positive values for grain yield per plant over standard check.

3.2.12 Harvest index (%)

Among 45 crosses evaluated, fourteen, eleven hybrids recorded positively significant heterosis over mid parent and standard check HD2968 respectively, for grain weight. The magnitude of heterosis ranges from (-.32.27) to HD3294 x (46.04) over mid parent. In present research, the highest positive and significant heterosis over mid parent was exhibited by cross HD3249 x DBW3059 followed by K1601 x HI153, HD3249 x DBW107, the cross HD187 x K0307 followed by K1601 x DBW107, BW107 x HD3059 shows highly positive values for 1000 grain weight over standard check. Significant positive heterosis for harvest index is has been reported by Jatoi et al. [13] and Yadav et al. [19].

4. CONCLUSION

The highest value for average heterosis and standard heterosis were (25.44) and (33.81) for grain yield per plant. Crosses DBW187 x HI153 followed by DBW187 x DBW3059, HD3294 x DBW3059, DBW187 x HD3059, K1317 x HD2967 manifested significant and positive heterosis over mid parent. The cross DBW187 x DBW3059 followed by DBW187 x HD3059, DBW187 x HI153 and HD3294 x K1601 shows highly positive standard heterosis for grain yield per plant over standard check HD2968. The above mentioned highly heterotic crosses also occupied top ranks in per se performance for grain yield per plant. The crosses which showed significant and positive over better parent heterosis and standard heterosis for grain yield per plant had also manifested significant in desired direction for one or more yield attributing characters. These hybrids may further be tested over various locations before release for commercial cultivation. High estimates of heterosis obtained in hybrid combinations revealed considerable genetic divergence among the parental lines and reveals good scope for commercial exploitation of heterosis in wheat.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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